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Determination of Series Resistance of Indium Phosphide Solar Cells

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The series resistance of a solar cell is an important parameter, which must be minimized to achieve high cell efficiencies. The cell series resistance is affected by the starting material, its design and processing. We have used the theoretical approach proposed by Jia, et al, to calculate the series resistance of indium phosphide solar cells. It is observed that the theoretical approach does not predict the series resistance correctly in all cases. We have modified the analysis to include the use of effective junction ideality factor. The calculated results have been compared with the available experimental results on indium phosphide solar cells processed by different techniques. It is found that the use of process dependent junction ideality factor leads to better estimation of series resistance. An accurate comprehensive series resistance model is warranted to give proper feedback for modifying the cell processing from the design state.

Introduction

The series resistance of a solar cell is an important parameter. An accurate knowledge of this parasitic parameter is highly essential for solar cell device processing and modeling. The cell series resistance is affected by the starting material, its design and processing. The series resistance must be minimized to achieve high cell efficiencies. Proper care should be taken to reduce the resistance offered by the front and back metal contacts, diffused and bulk regions of the cell. Though series resistance is an important quantity for solar cells operating at one sun conditions, it becomes very critical for cells working under high intensities of light and for solar cell arrays deployed for space missions near the sun. For these applications series resistance parameter becomes very critical due to large power loss at high currents. With the technological advances made in materials and cell process technologies, it has become possible to minimize the value of solar cell series resistance.

A number of theoretical approaches and experimental techniques are reported in the literature [refs. 1-10] for the determination of series resistance. It would not be possible to discuss the relative merits of various models in the present paper. In the present work we have used the theoretical approach proposed by Jia, et al [ref. 10] to calculate the series resistance of indium phosphide solar cells. Indium phosphide

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solar cells have shown great promise for space use due to their remarkable radiation resistance as compared to silicon and gallium-arsenide cells. A proper understanding of the series resistance of InP solar cells would lead to increased efficiencies.

It is observed that the theoretical approach [ref. 10] does not predict the series resistance correctly in all cases. We have modified the analysis to include the use of effective junction ideality factor. The calculated results have been compared with the available experimental results on indium phosphide solar cells processed by different techniques. It is found tht the use of process dependent junction ideality factor leads to better estimation of series resistance. An accurate comprehensive series resistance model is warranted to give proper feedback for modifying the cell processing from the design state.

Theoretical Approach

Starting with the theoretical I-V relation and under the relevant boundary conditions, the series resistance of a solar cell can be expressed as [ref. 10]:

$$R_s = \frac{V_m(i - I_m)}{I_m(i + I_m)} \qquad [1]$$

where $i = \frac{1}{V_t}(I_{sc} - I_m)[V_{oc} + V_t \ln(1 - I_m/I_{sc})]$
V_t = Thermal Voltage ($= kT/q$)
V_{oc} = Open – Circuit Voltage
I_{sc} = Short – Circuit Current
V_m = Maximum Power Point Voltage
I_m = Maximum Power Point Current

Calculations and Comparison with Experimental Results

For comparison we have considered the epitaxial base/epitaxial emitter indium phosphide solar cell processed by Spitzer, et al, of Spire Corporation [ref. 11] and measured at NASA Lewis Research Center under simulated AM0 conditions at 25°C. Table I describes the various parameters measured. By substituting the relevant parameter values from Table I into equation [1], the calculated value of the series resistance is 1.715 ohm. This value is in good agreement with the experimentally measured value of 1.748 ohm [ref. 11].

We have tried to calculate the series resistance of a number of solar cells using eq. [1] but it was observed that the calculated results estimate quite high values, which looked unrealistic. For example, we have considered the epitaxial base/ion implanted indium phosphide solar cell processed by Keavney, et al, of Spire Corporation [ref. 12] and measured at NASA Lewis Research Center. This is the best InP cell ever produced in the world to date. Table II describes the various parameters measured.

The eq. [1] gives the value of the series resistance equal to 19.69 ohm. This value is quite high and unrealistic for the best InP solar cell. The measured series resistance value for this cell is 1.06 ohm [ref. 13]. A relook of the Jia, et al's model [ref. 10] showed that the assumption of ideality factor, n equals to unity at V = Voc is not valid for all cases. It is proposed to use effective junction ideality factor, neff in the relation and the i term in eq. [1] modifies to the following

$$i = \frac{1}{V_t}(I_{sc} - I_m)[V_{oc}/n_{eff} + V_t \ln(1 - I_m/I_{sc})] \qquad [2]$$

Now using eq. (1) and modified relation for i as given by eq. [2] it is found that the calculated and measured series resistance values for Table II InP solar cell are in good agreement for n_{eff} equals to 1.46. This value suggests that the effective junction ideality factor is a process dependent parameter. The higher value of neff for the Table II solar cell shows that the ion-implantation for emitter might have generated more damage in the depletion region, as compared to MOCVD grown epitaxial emitter ($n_{eff} = 1$) leading to higher recombination current.

Conclusions

The theoretical approach of Jia, et al, [ref. 10] could determine the value of the solar cell series resistance reasonably well, if proper value of the junction ideality factor at cell open circuit voltage, mentioned in the present work as n_{eff} is known. Inclusion of the effect of recombination in the depletion region would yield a more comprehensive model. Further effort toward a simple and accurate solar cell series resistance modeling are in progress.

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Table I. MEASURED PARAMETERS OF EPITAXIAL BASE/EPITAXIAL EMITTER INDIUM PHOSPHIDE SOLAR CELL AT NASA LEWIS RESEARCH CENTER

[AMO, 137.2 mW/cm^2, 25^{o}C, Cell Area 0.25 cm^2]

Short Circuit Current	8.47 mA
Open-Circuit Voltage	868 mV
Maximum Power Point Current	8.19 mA
Maximum Power Point Voltage	751 mV
Maximum Power	6.15 mW
Fill Factor	0.838
Efficiency (Total Area)	17.94%

TABLE II MEASURED PARAMETERS OF EPITAXIAL BASE/IMPLANTED EMITTER INDIUM PHOSPHIDE SOLAR CELL AT NASA LEWIS RESEARCH CENTER

[AMO, 137.2 mW/cm^2, 25^{o}C, Cell Area 0.25 cm^2]

Short Circuit Current	8.93 mA
Open·Circuit Voltage	873 mV
Maximum Power Point Current	8.50 mA
Maximum Power Point Voltage	760 mV
Maximum Power	6.46 mW
Fill Factor	0.829
Efficiency (Total Area)	18.84 %